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Real time enhancement of low light images for low cost embedded platforms

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Abstract

Images captured at low light suffers from underexposure and noise. These poor-quality images act as hindrance for computer vision algorithms as well as human vision. While this problem can be solved by increasing the exposure time, it also introduces new problems. In applications like ADAS, where there are fast moving objects in the scene, increasing the exposure time will cause motion blur. In applications, that demand higher frame rate, increasing the exposure time is not an option. Increasing the gain will result in noise as well as saturation of pixels at higher end. So, a real time scene adaptive algorithm is required for the enhancement of low light images. We propose a real time low light enhancement algorithm with more detail preservation compared to existing global based enhancement algorithms for low cost embedded platforms. The algorithm is integrated to image signal processing pipeline of TI's TDA3x and achieved ~50fps on c66x DSP for HD resolution video captured from Omnivision's OV10640 Bayer image sensor.

Keywords *Low light enhancement, TDA3x, ISP, tone mapping, DSP*

Introduction

There have been several global and local statistics-based approach proposed in recent years for low light image enhancement. Previous works on low light image enhancement propose global and local enhancement methods. The local statistics-based algorithms are too slow and cannot be used for real time applications. The global statistics-based algorithms that work on very minimal statistics (mean, median, etc..) does not take the distribution of information. These global statistics-based algorithms stretch one or more regions of the histogram and shrink the other. In case of multi-modal histogram, the global statistics-based algorithm results in loss of information. This may pose a serious problem if there is a loss of details on the area of interest like a traffic sign or pedestrian in ADAS application. By carefully constructing the tone mapping curve used in global tone mapping, while the issue cannot be completely removed but can be considerably reduced. Given an underexposed image at extreme low light conditions, our objective is to perform real time adaptive tone mapping with high detail preservation on low power embedded systems.

Proposed Implementation Details

The proposed low light image enhancement algorithm consists of following steps:

- ***Dark channel subtraction***

Since image is captured at low light, it is bound to contain noise. The dark channel is calculated for each channel and then subtracted.

$$D = \min_{x,y \in \{0-W,\, 0-H\}} \{\min(R),\ \min(G1),\ \min(G2),\ \min(B)\}$$

$$DC = \begin{cases} D & if\ D < Thr \\ Thr & else \end{cases}$$

$$I_{Bayer}(x,y) = I(x,y) - DC$$

- ***Estimation of illumination map***

The illumination map is computed from input images by considering maximum of red, green and red channel:

$$I_{illMap}(x,y) = \max_{c \in \{R,G,B\}} I_c(x,y).$$

The illumination map is refined with 2x2 mean filter.

- ***Enhancement gain estimation***

The next step is to estimate the gain in the forms of LUT to enhance tonal and contrast based on the mean of the illumination map. The estimated gain will be similar to nonlinear transforms like log but with less steep slope of tone curve.

$$G(x,y) = \frac{(I_{illMap}(x,y)\ *(M_b + mean(\ I_{illMap})))}{(I_{illMap}(x,y) + mean(I_{illMap})}$$

Where $M_b$is maximum value for bit-depth b.

- ***Applying tone-mapping to the input image***

The resultant gain map is multiplied pixelwise with input Bayer image to result in the enhanced image $E_{BayerLLE}(x,y) = I_{Bayer}(x,y) * G(x,y)$.

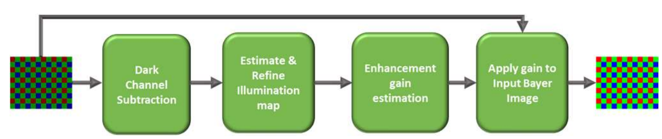

Figure 1: Core Low Light Enhancement Algorithm Flow

The algorithm is ported and optimized on TI's TDA3x camera pipeline with Processor SDK software. The core algorithm is optimized on c66x DSP using intrinsic to achieve real time performance. The rest of the image processing pipeline is executed by TDA3x Image Signal Processor (ISP) including noise filter.

The TDA3x SoC incorporates a heterogeneous, scalable architecture that includes a mix of TI's TMS320C66x digital signal processor (DSP) generation cores, Vision AccelerationPac and dual-Cortex-M4 processors (Figure 2).

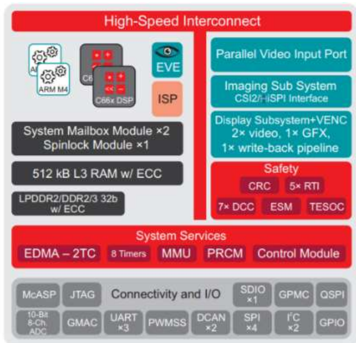

Figure 2: TDA3x functional diagram

The camera front end of TDA3x allows to capture Bayer data from image sensor which is fed to low light enhancement algorithm module running on c66x DSP. After the enhancement process, the output of DSP is fed to ISP to carry our normal Bayer signal processing operation. Note that the input and output format of the image is Bayer for low light enhancement algorithm module (Figure 3). The processed image/video can further be used depending on intended use cases.

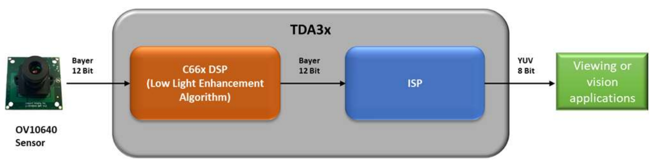

Figure 3: Low light enhancement in camera pipeline flow

Low light enhancement typically suffers from increased noise level. Although, it is possible to minimize noise by implementing the noise filter on DSP but real time performance may not be guaranteed due to complexity of noise filter algorithms. There are advanced hardware noise filter blocks present in ISP that can alleviate the problem of both noise filtering and real time performance. The noise filter blocks can be appropriately tuned for noise filter parameters to get the desired image or video quality. Figure 4 depicts the algorithm partitioning to leverage the noise filtering blocks in hardware.

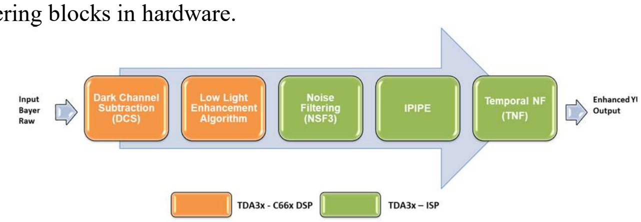

Figure 4: Algorithm Partitioning

Results

The low light enhancement algorithm is ported and optimized on TI's TDA3x System on Chip (SoC).

With low light enhancement algorithm, performance of vision algorithms improves significantly (Figure 5) apart from perceptual image quality improvement.

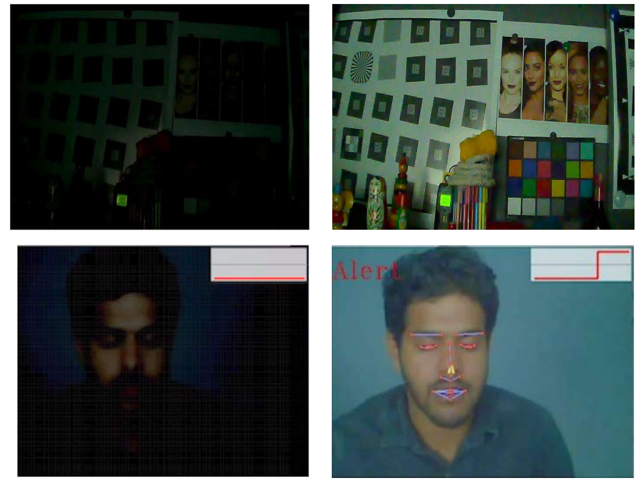

Figure 5: Results showing image quality improvement due to low light enhancement algorithm. Bottom set of images shows improvement of vision algorithm due to low light enhancement (left: without enhancement, right: with enhancement)

The algorithm is also generalized to work for offline RGB images to compare with traditional enhancement methods (Figure 6).

Figure 6: Comparison of enhancement techniques

The table 1 summarizes the overall achieved performance at real time camera system level. As shown, the algorithm can run real time for 720P resolution.

Table 1: Performance on TDA3x

Video Resolution	C66x DSP Load (@500MHz)	Time per frame (in milli seconds
1280x720	57%	18ms

The implemented algorithm is also measured for objective image quality metrics to validate the improvement achieved.
Two metrics are used: one is SSIM (Structured Similarity Index) which measures the perceptual difference between two similar images. For SSIM, two images are necessary. For comparison purpose, the metric is measured with the image taken at normal light which serves as reference image.
Other metric is color saturation or mean camera chroma which is the average chroma of camera colors divided by the average chroma of the ideal Colorchecker colors, expressed as a percentage.
Table 2 summarizes the IQ metrics measured at various low lux level.

Table 2: Image Quality Metrics at various lux levels

Intensity level in Lux	SSIM		Color Saturation	
	w/o LLE	With LLE	w/o LLE (%)	With LLE (%)
0.5	0.0060	0.3141	0.3	67.4
2	0.0834	0.6531	17.5	124.4
5	0.2511	0.6229	45.2	133

Conclusion

Previous works in tone mapping using cumulative histogram involves naive histogram equalization. We modify this problem to low light image enhancement based on illumination map. More details are preserved compared to the traditional approaches. The algorithm improves the effectiveness of vision algorithm significantly. Also, the resulting approach is computationally less intensive resulting in real time performance on embedded platform. The algorithm is also scalable to enhancement of images under monochrome or NIR images.

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